TITLE OF THE INVENTION

SCANNING EXPOSURE APPARATUS

FIELD OF THE INVENTION

The present invention relates to a scanning exposure technique, for example, suitable for manufacturing a device.

BACKGROUND OF THE INVENTION

In recent years, semiconductor devices such as an IC and LSI are highly integrated, and the semiconductor wafer micropatterning technique greatly advances along with this. Projection exposure apparatuses which play a central role in the micropatterning technique are an equal-magnification scanning exposure apparatus called a mirror projection aligner which exposes a mask and photosensitive substrate while scanning them by an equal-magnification mirror optical system having an arcuate exposure region, and a reduction projection exposure apparatus called a stepper which forms a mask pattern image onto a photosensitive substrate via a refraction optical system and exposes the photosensitive substrate by step & repeat.

Recently, a step & scan type scanning exposure apparatus which obtains high resolution and can increase the screen size is commercially available. An effective light source used in scanning exposure is a

pulse light source, e.g., excimer laser which emits pulses of short-wavelength light. To uniformly irradiate an irradiation surface with a pulse beam without any exposure nonuniformity while maintaining a uniform exposure amount on the irradiation surface in a scanning exposure apparatus using a pulse light source, it becomes important to properly set the pulse emission time and pulse emission interval of the pulse light source and their relationship with the irradiation surface moving velocity and the like.

In a conventional scanning exposure apparatus, no substrate is exposed in an acceleration section until the stage reaches a predetermined velocity from a still state in scanning and exposing a substrate, and a deceleration section until the stage reaches the still state from the predetermined velocity. In the conventional apparatus, the acceleration and deceleration sections do not contribute to exposure of a substrate, decreasing the throughput. Distances necessary for acceleration and deceleration must be ensured as a scanning range in addition to distances necessary for a reticle stage and wafer stage to pass through the illumination region. The moving ranges, i.e., moving strokes of the reticle stage and wafer stage become long. A prior art reference which gives attention to these problems is Japanese Patent Laid-Open No. 9-223662. In a scanning exposure apparatus

disclosed in this reference, an emission control means causes a light source means to emit pulses at a frequency proportional to the moving velocity of the irradiation surface in irradiating the irradiation surface with a pulse beam from the light source means. Exposure is done even during acceleration/deceleration of the stage, thereby increasing the throughput.

In exposure even during acceleration, the sync error between the wafer stage and the reticle stage (i.e., a moving average (MA) and moving standard deviation (MSD) known as exposure precision indices) is large immediately after the start of acceleration. No substrate can be exposed at high precision.

SUMMARY OF THE INVENTION

The present invention has been made in the above consideration, and has as its object to increase the exposure precision in a technique of exposing a substrate even during at least one of acceleration and deceleration of a substrate stage.

According to the first aspect of the present invention, there is provided a scanning exposure apparatus comprising a stage unit which supports and moves a substrate, and a control unit which starts exposing the substrate after a start of a second section in an acceleration section of the stage unit sequentially including a first section in which a jerk

is positive, the second section in which a jerk is 0, and a third section in which a jerk is negative.

In the preferred embodiment, a time ratio of the first section and the second section can be set to 3 : 2. Further, a time ratio of the first section, the second section, and the third section can be set to 3 : 2 : 3. The first section and the third section can be set to uniform-jerk sections.

In the preferred embodiment, the control unit can start exposing the substrate after the stage is accelerated to a velocity which is over 30% of a final velocity in the acceleration section.

In the preferred embodiment, a uniform-velocity section of the stage unit follows the acceleration section.

According to the second aspect of the present invention, there is provided a scanning exposure apparatus comprising a stage unit which supports and moves a substrate, and a control unit which ends exposing the substrate before an end of a five section in a deceleration section of the stage unit sequentially including a fourth section in which a jerk is negative, the fifth section in which a jerk is 0, and a sixth section in which a jerk is positive.

In the preferred embodiment, a time ratio of the fifth section and the sixth section can be set to 2 : 3. Further, a time ratio of the fourth section, the

fifth section, and the sixth section can be set to 3 : 2 : 3. The fourth section and the sixth section can be set to uniform-jerk sections.

In the preferred embodiment, the control unit ends exposing the substrate before the stage unit is decelerated to a velocity which is 30% of an initial velocity in the deceleration section.

In the preferred embodiment, a uniform-velocity section of the stage unit precedes before the deceleration section.

According to the third aspect of the present invention, there is provided a scanning exposure method of exposing a substrate while moving a stage which supports the substrate, comprising steps of moving the stage in accordance with a profile of an acceleration section of the stage sequentially including a first section in which a jerk is positive, a second section in which a jerk is 0, and a third section in which a jerk is negative, and starting exposing the substrate after a start of the second section in the acceleration section.

According to the fourth aspect of the present invention, there is provided a scanning exposure method of exposing a substrate while moving a stage which supports the substrate, comprising steps of moving the stage in accordance with a profile of a deceleration section of the stage sequentially including a fourth

section in which a jerk is negative, a fifth section in which a jerk is 0, and a sixth section in which a jerk is positive; and ending exposing the substrate before an end of the five section in the deceleration section.

According to the fifth aspect of the present invention, there is provided a device manufacturing method comprising a step of exposing a substrate to a pattern using the above scanning exposure apparatus.

Other features and advantages of the present invention will be apparent from the following description taken in conjunction with the accompanying drawings, in which like reference characters designate the same or similar parts throughout the figures thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

Fig. 1 is a schematic view showing main part of a scanning exposure apparatus according to the first embodiment of the present invention;

Fig. 2 is a schematic view showing main part of a scanning exposure apparatus according to the second embodiment of the present invention;

Figs. 3A to 3C are graphs showing the relationship between the reticle stage moving velocity, the wafer stage moving velocity, and pulse emission;

Fig. 4 is a graph showing an acceleration change in the acceleration section;

Fig. 5 is a graph showing the relationship between the MSD value and a lens CD change; and

Fig. 6 is a view showing the stage acceleration (Acc), velocity (Vel), sync precision (Sync), moving average (MA), and moving standard deviation (MSD).

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In this specification, a section (section in a term such as a moving section, acceleration section, uniform-velocity section, or deceleration section) means a temporal period or an interval between two positions in the three-dimensional space.

Preferred embodiments of the present invention will be described below with reference to the accompanying drawings.

(First Embodiment)

Fig. 1 is a schematic view showing main part of a scanning exposure apparatus according to the first embodiment of the present invention. The scanning exposure apparatus can include various types of exposure apparatuses such as a step & scan type scanning exposure apparatus (so-called scanner) and

mirror projection aligner that scan and expose a substrate to transfer a master pattern onto the substrate while moving the substrate and master.

A scanning exposure apparatus 50 according to a preferred embodiment of the present invention is suitable for manufacturing semiconductor devices (e.g., IC and LSI), liquid crystal devices, image sensing devices (e.g., CCD), and various devices (e.g., magnetic head).

As a light source 1, the scanning exposure apparatus 50 shown in Fig. 1 can adopt, e.g., an excimer laser which emits a pulse beam. The present invention will be exemplified for a pulse light source serving as the light source 1. A beam emitted by the light source 1 is shaped into a desired beam shape via a beam shaping optical system 2. The beam is guided to a light incident surface 3a of an optical integrator 3 formed by a fly-eye lens or the like. The optical integrator 3 is formed by two-dimensionally arraying a plurality of microlenses at a predetermined pitch. A plurality of secondary light sources are formed near a light exit surface 3b.

Each secondary light source formed near the light exit surface 3b of the optical integrator 3 Köhler-illuminates a masking blade 5 having a plurality of movable blades (light-shielding members) via a condenser lens 4. For example, the masking blade 5

forms a slit-shaped aperture by opposing edges of four movable blades.

The beam having passed through the masking blade 5 is focused via an imaging lens 6 on a reticle (master) 9 set on a reticle stage 11. The beam illuminates a slit-shaped region out of the entire region of the reticle 9. A mirror 7 is interposed between the condenser lens 6 and the reticle 9, and the optical path of the beam having passed through the condenser lens 6 is deflected by the mirror 7 toward the reticle 9. A pattern formed on the reticle 9 is reduced and projected onto a wafer (substrate) 10 such as a semiconductor wafer set on a wafer stage 12 via a projection optical system 8.

In the first embodiment, the masking blade 5 and reticle 9 are almost conjugate to each other via an optical system formed by the imaging lens 6 and mirror 7. The vicinity (secondary light source plane) of the exit surface 3b of the optical integrator 3 and the pupil plane of the projection optical system 8 are almost conjugate to each other via an optical system formed by the condenser lens 4 and imaging lens 6.

Exposure operation and relevant operation in the scanning exposure apparatus 50 are controlled by a control unit 100. The control unit 100 comprises a stage position measurement unit 101, stage sync movement control unit 102, time interval calculation

unit 103, memory unit 104, and pulse emission time control unit 105.

In scanning/exposure, the stage sync movement control unit 102 controls the reticle stage (master stage) 11 and wafer stage (substrate stage) 12 (these stages will also be simply referred to as stages hereinafter) so as to move at a ratio corresponding to the magnification of the projection optical system 8. For example, when the magnification of the projection optical system 8 is -1/4, the stage sync movement control unit 102 controls the reticle stage 11 and wafer stage 12 so as to move in opposite directions at a velocity ratio of 4 : 1. The stage sync movement control unit 102 obtains position data or position signals representing the current positions of the stages 11 and 12 from the stage position measurement unit 101 which measures the positions of the stages 11 and 12, and controls the positions of the stages 11 and 12 on the basis of the position data or position signals. The stage sync movement control unit 102 controls movement of the stages 11 and 12 so as to sequentially scan and expose a plurality of exposure regions on the wafer 10. The moving sections of the stages 11 and 12 in scanning/exposure of each exposure region are defined by an acceleration section, uniform-velocity section, and deceleration section.

The stage position measurement unit 101 comprises

a velocity detection unit 101a which differentiates by the time the position data or position signals of the stages 11 and 12 to obtain the velocities of the stages 11 and 12. The velocity detection unit 101a may be formed not as a building component of the stage position measurement unit 101 but as another building component.

The time interval calculation unit 103 calculates a pulse emission time interval on the basis of data representing a velocity provided by the velocity detection unit 101a. The pulse emission time interval is so determined as to set the product of the velocity of the stage 11 or 12 and the time interval to a predetermined value. This means that the pulse emission time interval is so determined as to make the velocity of the stage 11 or 12 and the pulse emission frequency proportional to each other.

The memory unit 104 stores the immediately preceding pulse emission time. The pulse emission time control unit 105 comprises a time calculation unit 105a which determines the next pulse emission time on the basis of the pulse emission time interval provided from the time interval calculation unit 103 and the immediately preceding pulse emission time stored in the memory unit 104, and an emission driving unit 105b which controls the pulse emission time of the pulse light source 1 (i.e., emits a pulse at the next pulse

emission time). The next pulse emission time determined by the time calculation unit 105a is stored (typically overwritten) in the memory unit 104.

As described above, the exposure apparatus 50 causes the pulse light source 1 to emit pulses at a frequency proportional to the moving velocities of the stages 11 and 12 under the control of the control unit 100. Even during acceleration/deceleration of the stages 11 and 12 in relative movement of the reticle stage 11 (reticle 9) and wafer stage 12 (wafer 10) under the control of the control unit 100, the exposure apparatus 50 causes the pulse light source 1 to emit pulses at a frequency proportional to the moving velocities (scanning velocities) of the stages 11 and 12 (time interval inversely proportional to the moving velocities), thereby scanning the wafer 10 and exposing it to the pattern of the reticle 9. According to the first embodiment, the wafer 10 is exposed even during acceleration/deceleration of the stages 11 and 12, thereby increasing the throughput and shortening the moving strokes of the stages 11 and 12. Further, the pulse light source 1 emits pulses at a frequency proportional to the moving velocities (scanning velocities) of the stages 11 and 12 (time interval inversely proportional to the moving velocities). In other words, the pulse oscillation cycle of the pulse light source 1 is changed in accordance with the moving

velocities of the stages 11 and 12. This can correct exposure nonuniformity caused by variations in the moving velocities of the stages 11 and 12.

In the first embodiment, the control unit 100 controls exposure operation such that exposure of the wafer 10 with a pulse beam in the moving sections (scanning sections) of the stages 11 and 12 that are defined by an acceleration section, subsequent uniform-velocity section, and subsequent deceleration section is not performed in all the acceleration section, uniform-velocity section, and deceleration section, but starts during the acceleration section (more specifically, after the exposure precisions (e.g., MA and MSD) of the stages 11 and 12 fall within the allowance in the acceleration section). This can realize an increase in throughput, shortening of the stage moving stroke, and maintenance of the exposure precision. The scanning/exposure end timing of the wafer 10 is preferably the end point of the uniform-velocity section in terms of maintenance of the exposure precision, but preferably a point during the deceleration section in terms of an increase in throughput.

The acceleration section is a section in which the stages 11 and 12 are moved at a positive acceleration. The uniform-velocity section is a section in which the stages 11 and 12 are moved at an

almost uniform velocity. The deceleration section is a section in which the stages 11 and 12 are moved at a negative acceleration.

A method of starting wafer exposure during stage acceleration described above will be explained in more detail.

When the energy amounts of pulse beams emitted by the pulse light source 1 to the wafer 10 are almost uniform, a cumulative exposure amount (target exposure amount) P on the wafer is given by equation (1). Note that "*" represents a multiplication sign.

$$P = q*n*Bx/Vx \qquad \ldots(1)$$

where q is the wafer exposure amount by one pulse emission, n is the pulse emission frequency meaning the number of pulses emitted per unit time by the pulse light source 1, Bx is the illumination region width on the wafer that is defined by the masking blade 5, and Vx is the moving velocity of the wafer (wafer stage 12).

A pulse emission frequency n for keeping the cumulative exposure amount P constant on the wafer is given by

$$n = P*Vx/(q*Bx) \qquad \ldots(2)$$

Since q, Bx, and P are constant values, the pulse emission frequency n is proportional to the wafer moving velocity Vx.

The relationship between the pulse emission

frequency n and a pulse emission time interval Δt meaning the time interval between two pulse emission operations adjacent to each other on the time axis is given by

$$\Delta t = 1/n \qquad \ldots(3)$$

A distance Δx by which the wafer (wafer stage) moves within the pulse emission time interval Δt is given by equation (4). Equation (2) is substituted into equation (4) to find that Δx is a constant value.

$$\begin{aligned}\Delta x &= \Delta t * Vx \qquad \ldots(4)\\ &= Vx/n\\ &= q*Bx/P = \text{constant}\end{aligned}$$

Since the reticle stage 11 and wafer stage 12 have a predetermined velocity ratio equal to a magnification <u>a</u> of the projection optical system 8, a distance Δy by which the reticle moves is given by

$$\Delta y = \Delta x/a \qquad \ldots(5)$$

That is, to keep the cumulative exposure amount P constant on the wafer even upon changes in the velocities of the stages 11 and 12, pulse emission is controlled such that any one of the pulse emission frequency n, pulse emission time interval Δt, wafer moving distance Δx, and reticle moving distance Δy satisfies equations (2) to (5) representing various conditions.

Figs. 3A to 3C are graphs showing the relationship between the reticle stage velocity, the

wafer stage velocity, and the pulse emission time of the pulse light source 1 when the reticle stage 11 and wafer stage 12 are moved in synchronism with each other in the preferred embodiment of the present invention.

Fig. 3A shows the velocity of the reticle stage 11. Fig. 3B shows the velocity of the wafer stage 12. Fig. 3C shows a change in pulse emission frequency during scanning. The stages 11 and 12 are synchronized with each other, and the pulse emission frequency is determined in accordance with the velocities of the stages 11 and 12. A wafer can be exposed at a constant cumulative exposure amount not only when the stages 11 and 12 keep predetermined velocities (uniform-velocity section), but also when pulse emission is done during acceleration/deceleration (acceleration section/deceleration section).

Fig. 6 is a view showing a stage acceleration Acc, a stage velocity Vel, a sync precision Sync between the reticle stage 11 and the wafer stage 12, an exposure slit width moving average MA, and a moving standard deviation MSD when the reticle stage 11 and wafer stage 12 are moved in synchronism with each other. The acceleration sections of the stages 11 and 12 are formed by three sections: an acceleration-up section A, uniform-acceleration section B, and acceleration-down section C. The uniform-velocity sections of the stages 11 and 12 are a section D, and

their deceleration sections are formed by sections E, F, and G. In Fig. 6, the sync precision Sync, moving average MA, and moving standard deviation MSD have large values in the section A, but small values in the section B because of no force change. As is apparent from a section Expo (from the start of the section B to the end of the section F) in Fig. 6, exposure can start from the section B.

Fig. 5 is a graph showing the relationship between the moving standard deviation MSD depending on the stage sync precision and the critical dimension (CD) of the exposure pattern for an ArF laser and KrF laser serving as the pulse light source 1. As the MSD increases, the CD decreases. If the MSD value is 10 nm or less, a decrease in CD value is as small as 2 nm, practically posing no problem. In Fig. 6, the MSD after the section B is 6 nm or less, and a decrease in CD is about 1 nm in Fig. 5. Hence, the start of exposure at the start of the section B or during the section B hardly influences the exposure precision.

In Fig. 6, the accelerations in the jerk sections (sections in which the jerk is not 0) A, C, E, and G change linearly (the jerk is constant), but points at which the jerk is discontinuous exist, and the stages greatly swing at these discontinuous points. In order to eliminate a discontinuous change in jerk and reduce the swing of the stages 11 and 12, a jerk profile based

on a multidimensional function or trigonometric function is preferably used. In this case, the MSD after the section B further decreases, and the CD value also further decreases.

Fig. 4 is a graph showing details of the acceleration section. The abscissa represents the time t, the ordinate represents the acceleration Acc, and the maximum acceleration is set to G. The stage velocity after the acceleration-up time J is equal to the area of a triangle having a base J and height G, and S1/2 for J*G = S1. The stage velocity variation during the uniform-acceleration time K is equal to the area of a rectangle having one side K and the other side G, and K*G = S2. The stage velocity variation during the acceleration-down time J is S1/2. A final stage velocity v is therefore given by

$$v = S1 + S2 = G(J + K) \qquad \ldots(6)$$

That is, the sum of the acceleration change time J and uniform-acceleration time K is uniquely determined by the highest acceleration G and stage velocity v:

$$v/G = J + K \qquad \ldots(7)$$

The time until the stages 11 and 12 reach target velocities (velocities in the uniform-velocity section) after the start of accelerating the stages 11 and 12 is (2J + K). A shorter K (i.e., longer J) prolongs the acceleration time, decreasing the throughput. A

shorter J greatly changes the jerks of the stages 11 and 12 or the jerk at discontinuous jerk points, decreasing the sync precision. From this, an optimal ratio R of J and K in Fig. 4 exists, and experiments reveal that $R = K/J = 2/3$ is preferable. For example, 1) when the highest acceleration of the reticle stage 11 is 2G and the velocity is 1 m/sec, J = 30 msec and K = 21 msec are preferable. 2) When the highest acceleration of the reticle stage is 2.8G and the velocity is 1.4 m/sec, J = 30 msec and K = 21 msec are preferable.

For $R = 2/3$, letting V be the stage velocity (stage velocity in the uniform-velocity section) at the end of accelerating the stages, a stage velocity Vp at an end point P of the acceleration-up section in Fig. 4 is given by

$$Vp = 0.3\ V \qquad \ldots(8)$$

As described above, according to the preferred embodiment of the present invention, wafer exposure preferably starts at the start of the section B or during the section B in Fig. 6. Considering equation (8), exposure preferably starts when the stages are accelerated in the acceleration section to predetermined velocities which are 30% or more of the stage velocities in the uniform-velocity section. As for wafer exposure in the deceleration section, the wafer is preferably exposed until the stages are

decelerated to predetermined velocities which are 30% or more of the stage velocities in the uniform-velocity section.

More specifically, according to the preferred embodiment of the present invention, the control unit 100 controls exposure operation so as to start wafer exposure when the velocities of the stages 11 and 12 in the acceleration section are increased to predetermined velocities which are 30% or more of the target velocities of the stages 11 and 12 in the uniform-velocity section. Also, the control unit 100 controls exposure operation so as to complete wafer exposure when the velocities of the stages 11 and 12 in the deceleration section are decreased to predetermined velocities which are 30% or more of the velocities of the stages 11 and 12 in the uniform-velocity section.

In this way, wafer exposure starts during the acceleration section, and more preferably wafer exposure is performed in a section which starts during the acceleration section and ends during the deceleration section via the uniform-velocity section. This can shorten the time which does not contribute to exposure, and increase the throughput while keeping the exposure precision high. A conventional exposure apparatus must move the stages by an extra distance corresponding to the entire stage acceleration section and entire deceleration section. To the contrary, the

exposure apparatus according to the preferred embodiment of the present invention can shorten the moving strokes (stage moving distances) of the stages 11 and 12.

(Second Embodiment)

Fig. 2 is a schematic view showing main part of a scanning exposure apparatus according to the second embodiment of the present invention. In the first embodiment, the light source 1 emits pulses at a frequency proportional to the stage moving velocity. In the second embodiment, a light source 1 emits pulses every time a stage moves by a preset distance. The remaining arrangement and control in the second embodiment are the same as those in the first embodiment.

A scanning exposure apparatus 50' shown in Fig. 2 according to the second embodiment of the present invention comprises a control unit 100' instead of the control unit 100 shown in Fig. 1. The control unit 100' comprises a stage position measurement unit 101, stage sync movement control unit 102, memory unit 106, and pulse emission position control unit 107.

The memory unit 106 stores information representing the position of a reticle stage 11 or wafer stage 12 (or the positions of them) immediately when the light source 1 emits a pulse. The pulse emission position control unit 107 comprises a moving

distance calculation unit 107a which calculates a distance by which the reticle stage 11 or wafer stage 12 moves immediately after pulse emission, on the basis of position information stored in the memory unit 106, and an emission driving unit 107b which causes the pulse light source 1 to emit pulses when the moving amount of the reticle stage 11 or wafer stage 12 reaches a predetermined moving amount. The remaining arrangement of the control unit 100' is the same as that in the first embodiment, and a description thereof will be omitted.

(Application)

The above-described scanning exposure apparatus and scanning exposure method can increase the throughput while maintaining high exposure precision. A device manufacturing method which adopts the apparatus and method also exhibits new, useful effects.

The device manufacturing method according to this application includes a step of scanning and exposing a substrate (e.g., wafer (semiconductor wafer) or glass plate) coated with a photosensitive agent to transfer a pattern onto the substrate by applying the scanning exposure apparatus and method, and a step of developing the photosensitive agent of the substrate. By using the developed photosensitive agent as a mask pattern, for example, a lower layer is processed (e.g., etched) to form a desired pattern. This lithography process,

etching, and another process are repeated to obtain a desired device.

As many apparently widely different embodiments of the present invention can be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific embodiments thereof except as defined in the claims.